LLRF system for the HIE-Isolde

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with valuable help of
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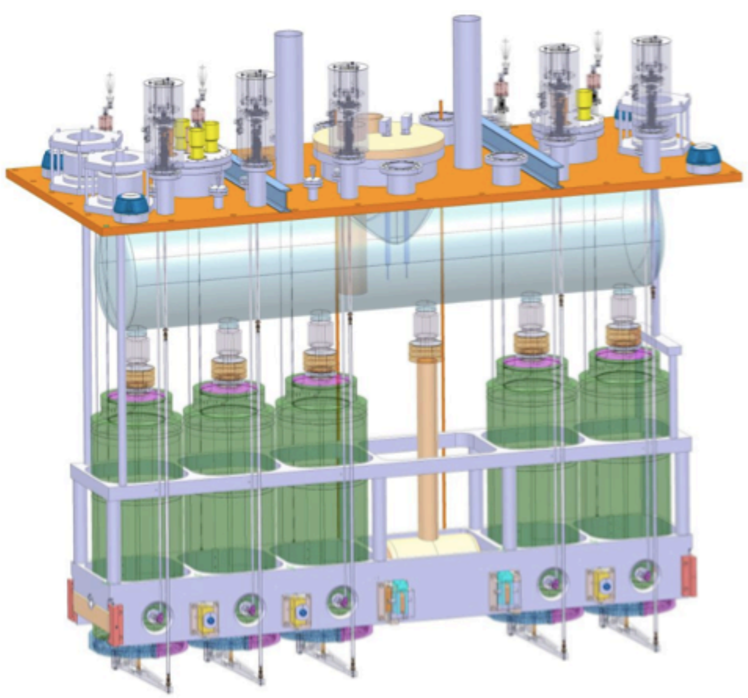
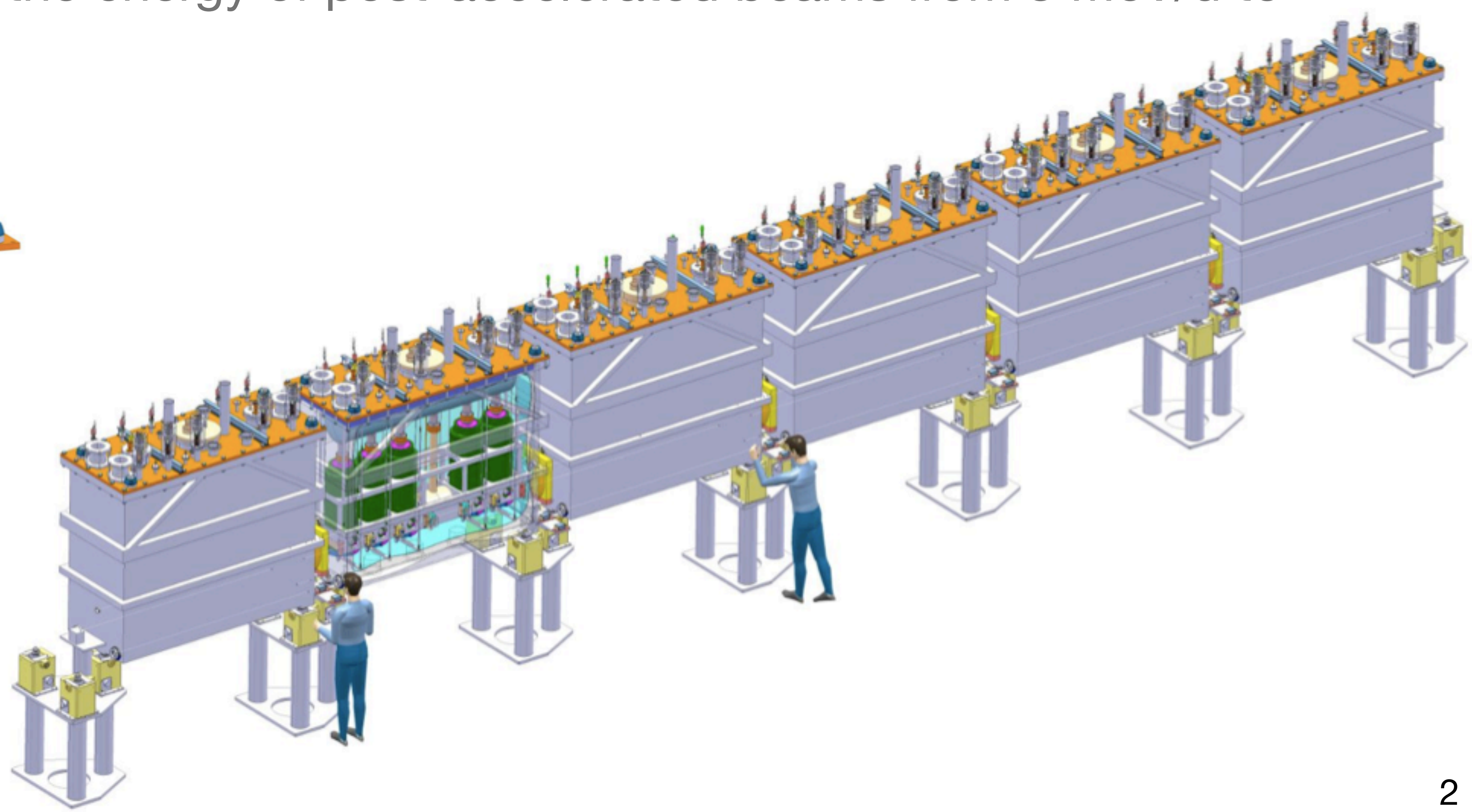
HIE-Isolde project at CERN

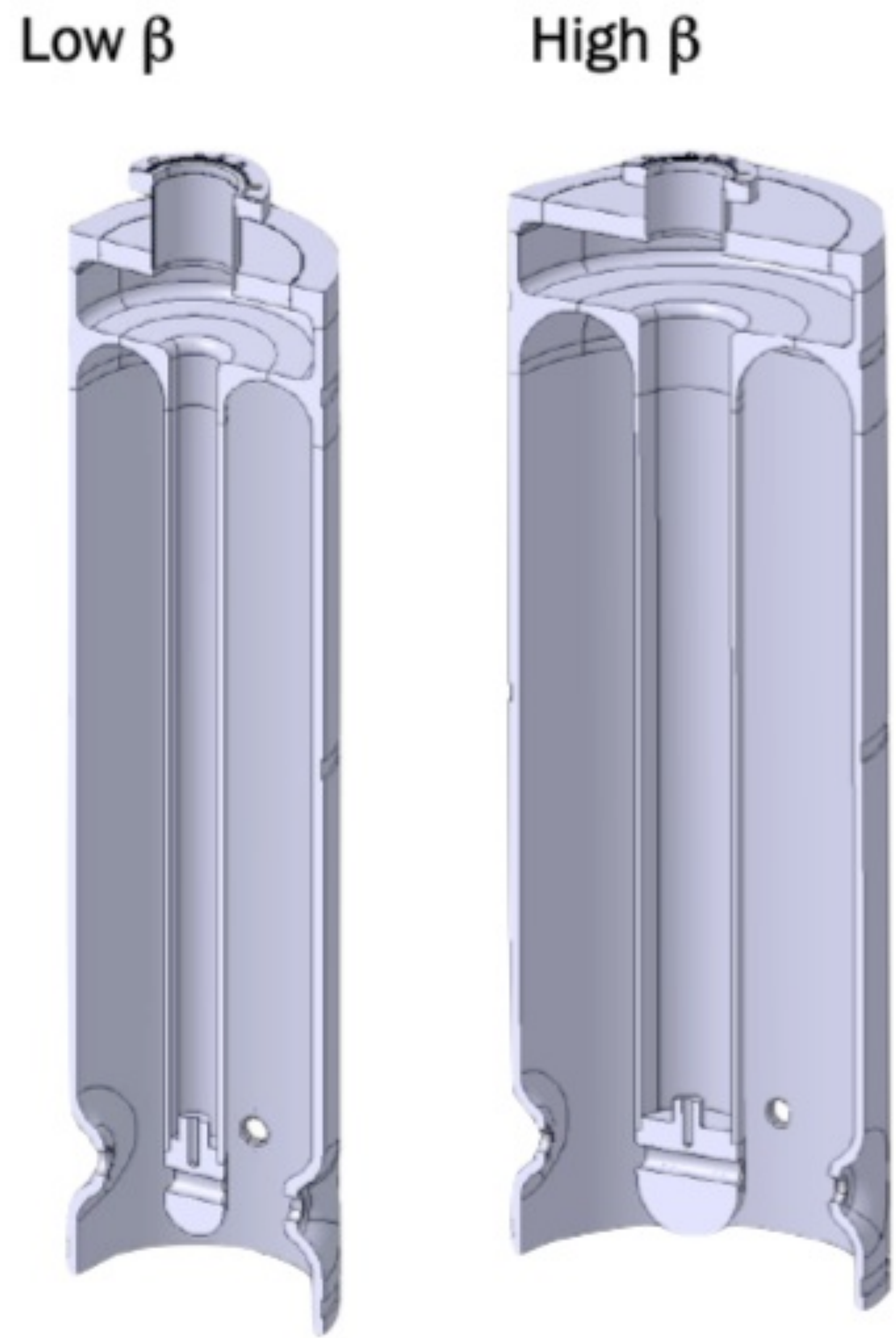
- HIE-Isolde is a major upgrade of the radioactive beams facility at CERN
- 40 MV superconducting linac based on 32 independently phased superconducting quarter-wave resonators
- The linac will raise the energy of post-accelerated beams from 3 MeV/u to over 10 MeV/u.





HIE-Isolde RF system

- Nb on copper sputtered, quarter wave resonators
- RF dissipation 10 W at nominal 6 MV/m accelerating gradient
- Very narrowband operation (0.1...15 Hz BW)
- Common beam and insulation vacuum
- Aim at a very low maintenance controls
  - OFF -> cavity start -> RF ON
- Fully automatic cavity phasing for different ion species



HIE-Isolde LLRF system architecture

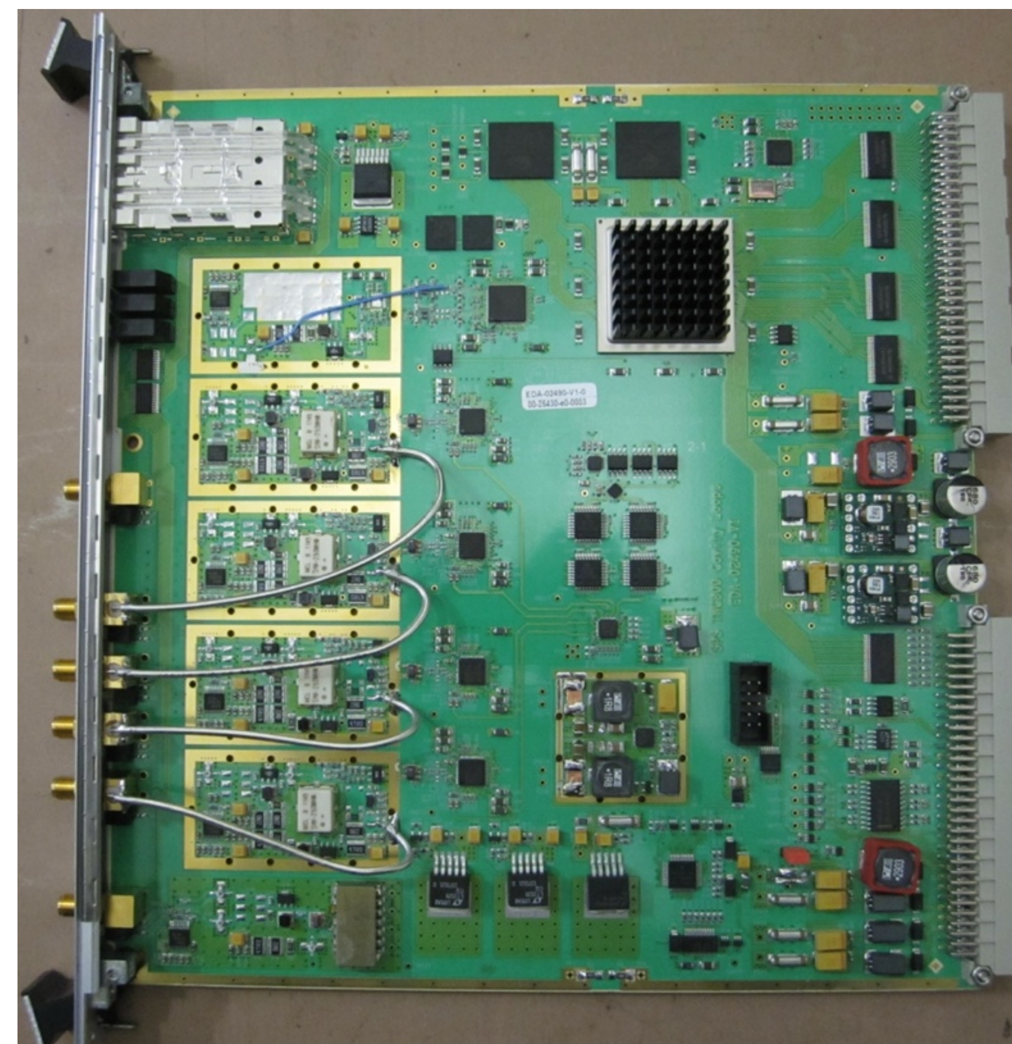
- Operating frequency of 101.28 MHz is comfortable for
  - direct RF sampling by ADC
  - direct RF generation by DAC
  - clever sampling frequency choice allows for direct digital IQ demodulation
- The complexity is shifted from the RF hardware to the FPGA code

- LHC based design - FPGA, observation memories, custom backplane
- Whole LLRF for 32 cavities with all house keeping fits into 7 VME crates

HIE-Isolde LLRF system architecture

LLRF test stand

HIE Isolde LLRF controller, version 0



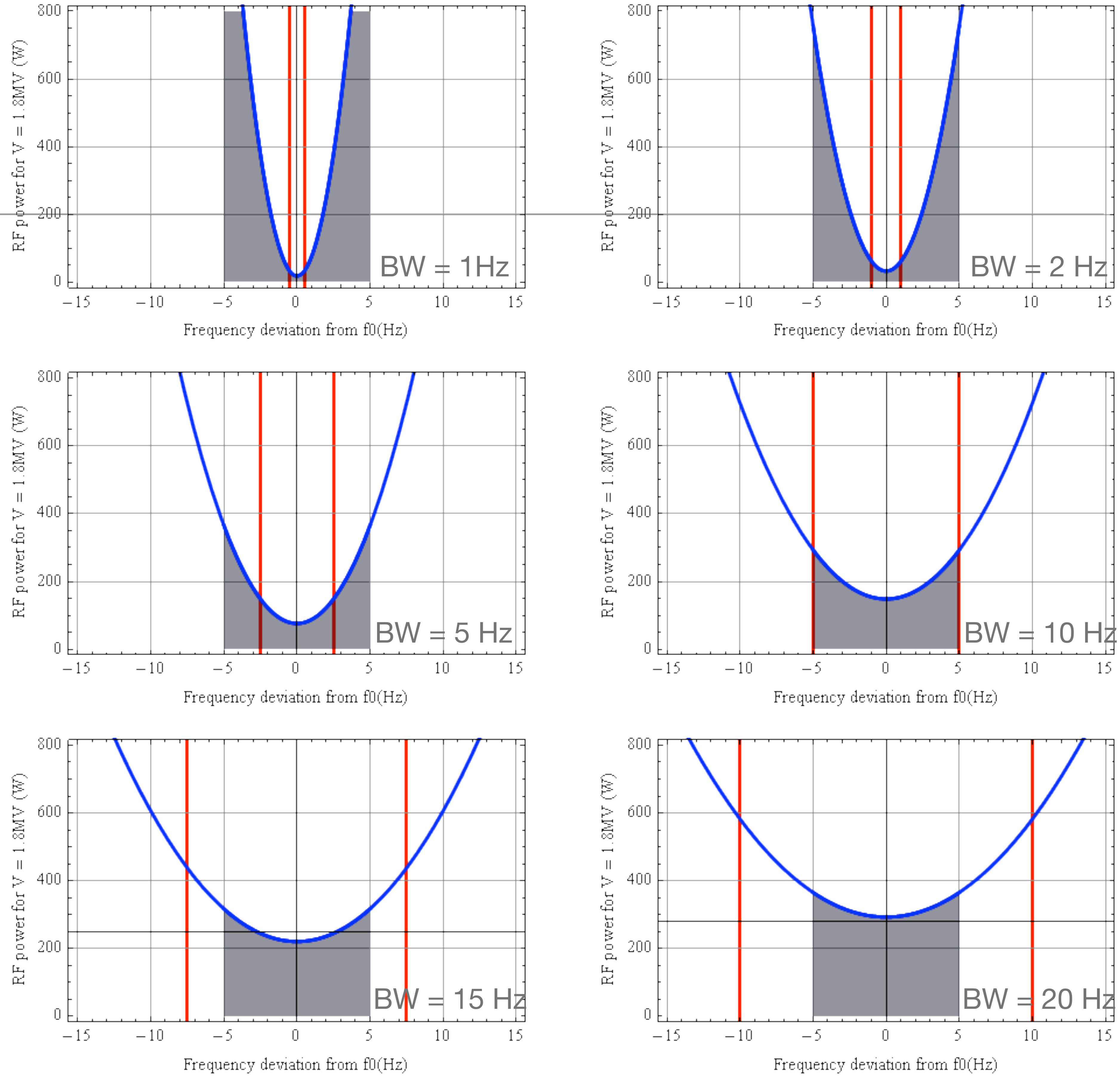
D. Valuch, M. Elias: LLRF system for the HIE-Isolde.
LLRF 2013 workshop, October 2013, Lake Tahoe, California.

Challenges to the LLRF system

- Very narrow bandwidth operation
  - Cavity intrinsic BW <0.1 Hz
  - Operating BW 1..10Hz
- Large span, yet very fine resolution mechanical tuner:
  - Full range ~24 kHz
  - but... step size ~0.3 Hz (deformation ~40 nm/step)

- Initial worry: ***microphonics*** will be the crucial factor for the cavity operation
- Instead, the ***Lorentz force detuning*** (LFD) of the tuning plate turned out to be the killer

HIE-Isolde cavity power requirement to obtain nominal gradient 6 MV/m



Red - desired operating bandwidth

Gray - simulated microphonics

Blue - power required for 6 MV/m

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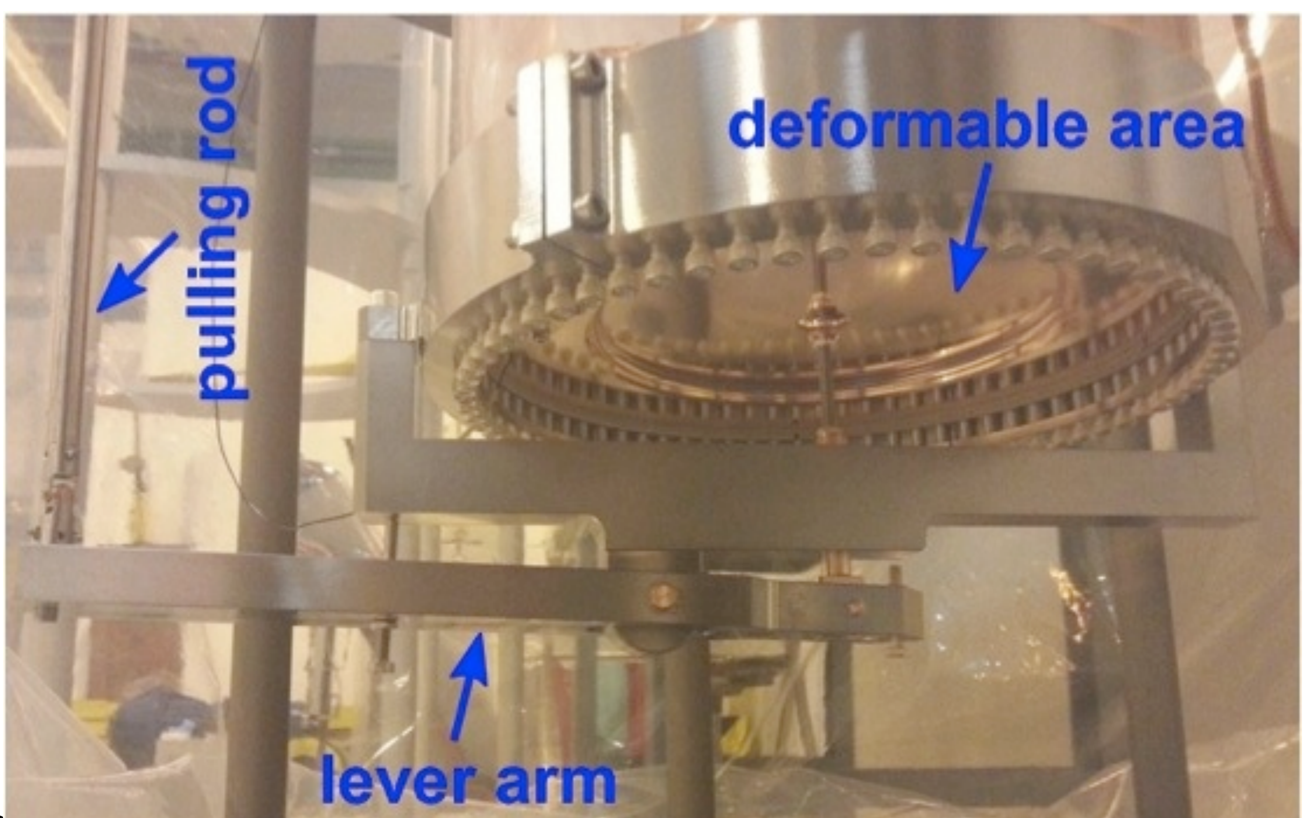
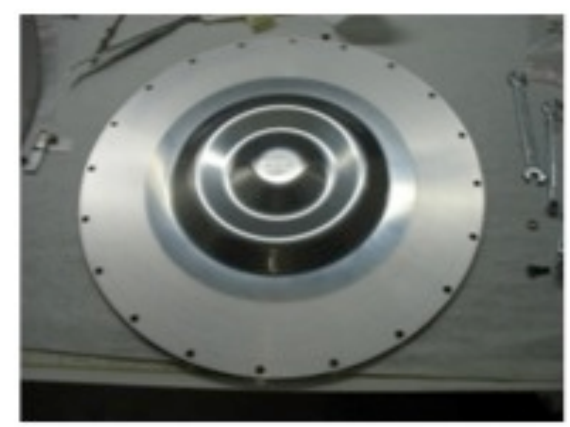
Cavity tuning plate and L.f. detuning

- Tuner has to compensate
  - the cavity fabrication tolerances (coarse setting)
  - frequency shift due to the main coupler loading (from intrinsic BW (0.1Hz) to operating BW (10-15 Hz))
  - frequency shift due to helium pressure and cryostat drift

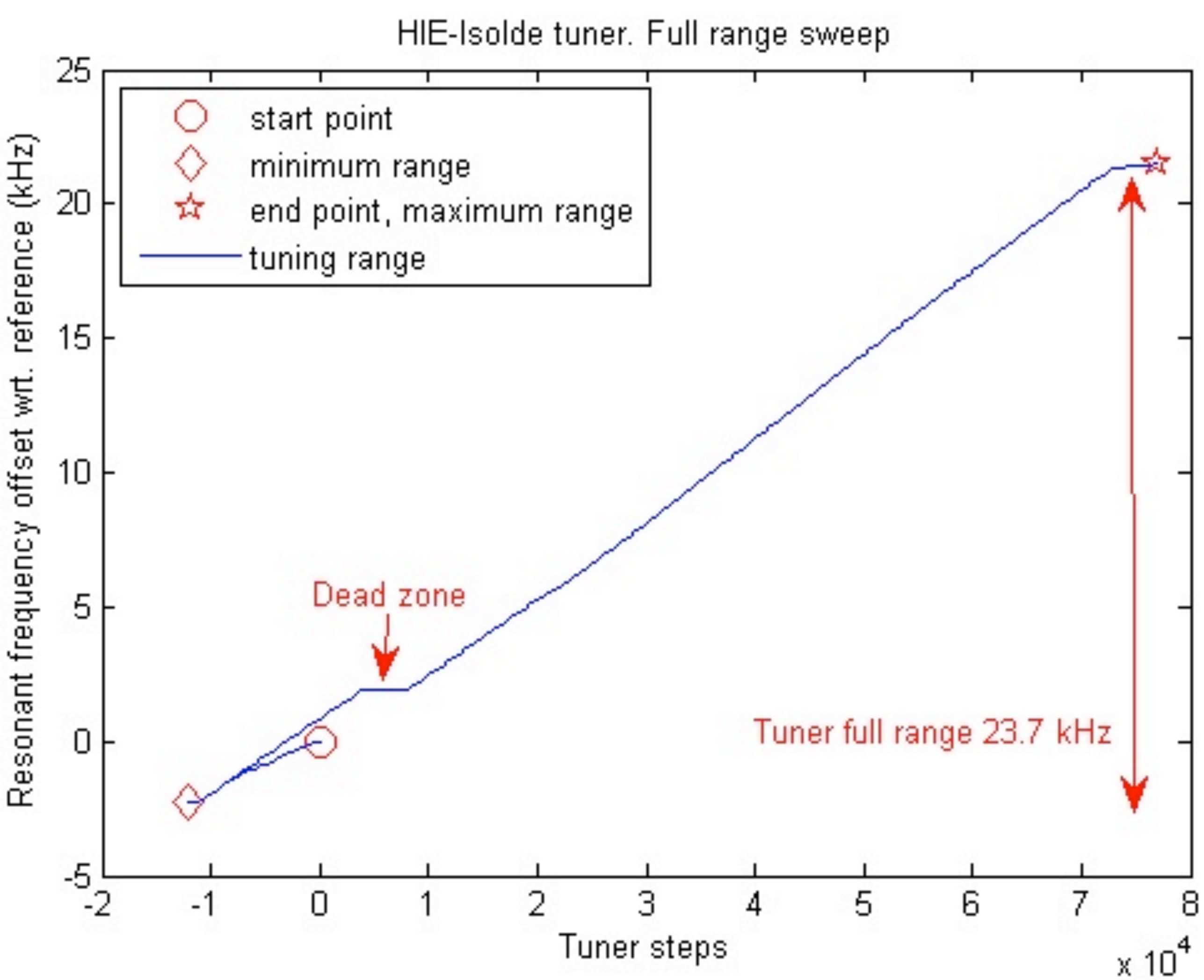


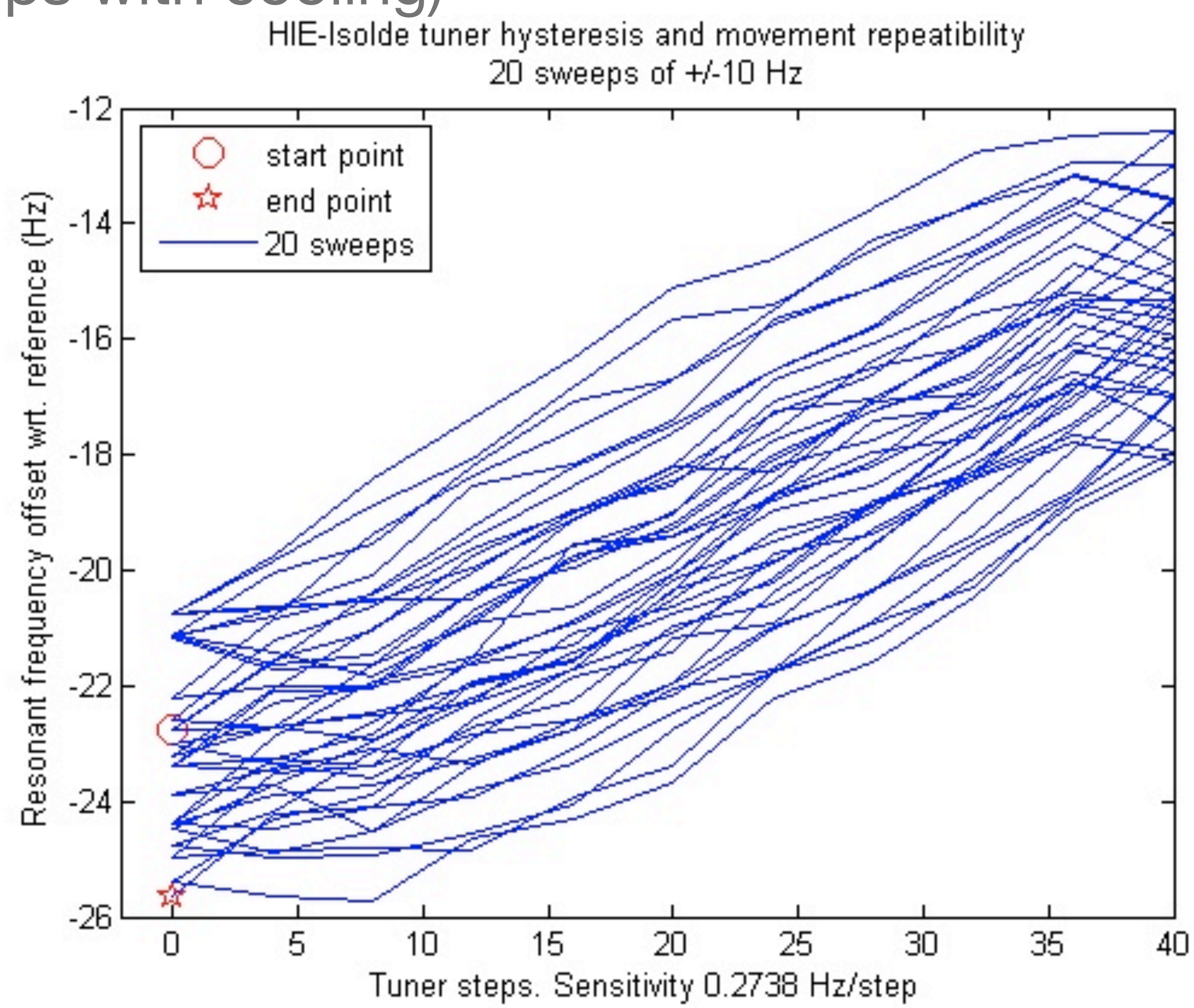


Photos: I. Mondino, W. Venturini, P. Zhang

Cavity tuning plate and L.f. detuning

- Current tuner design suffers of dead zone and hysteresis
- But the main killer is Lorentz force detuning
- Ongoing work to improve it (also helps with cooling)





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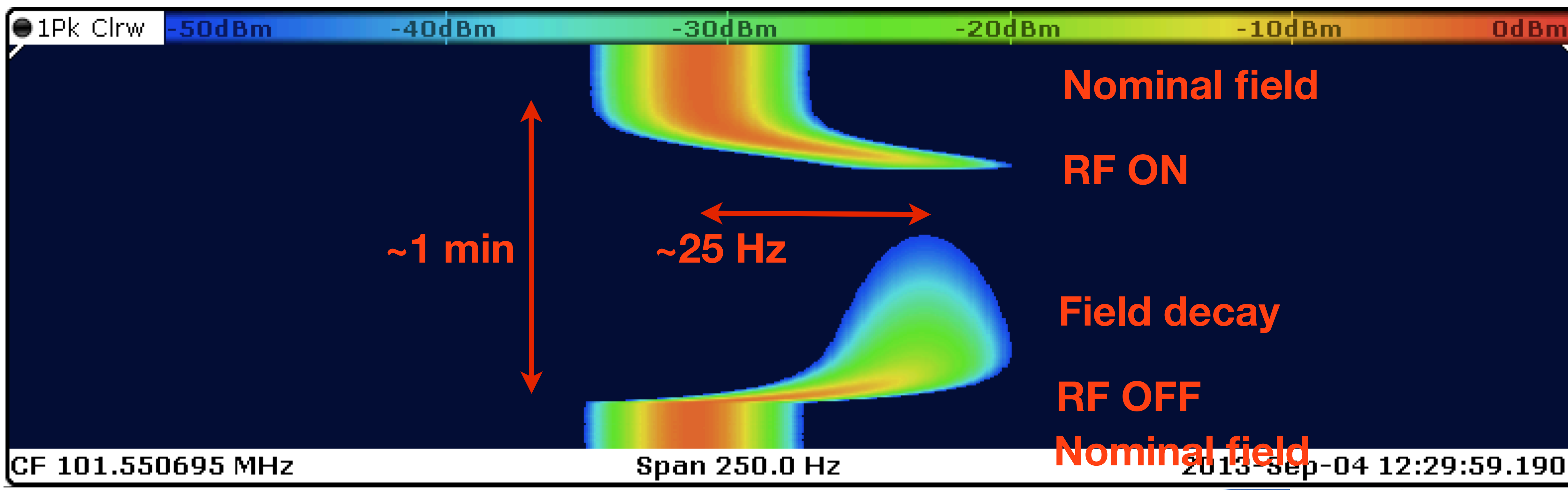
Cavity start-up

- In two words: ***VERY TRICKY***
  - 0.1Hz bandwidth resonator could sit anywhere within the 30kHz range
  - Once some field is in, the LFD will push the resonant frequency off by tens of bandwidths
  - Self Excited Loop (SEL) helps to start the cavity



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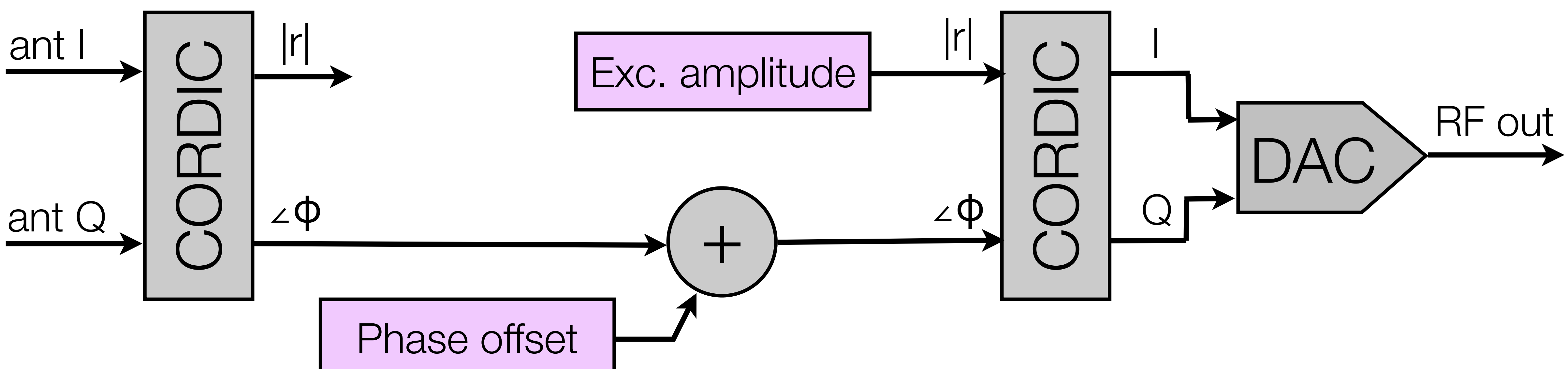
Self excited loop (SEL)

- Very useful concept for narrowband cavities and/or cavities with large LFD
  - starting up the cavity
  - conditioning
- Precise control of the forward injected power, brigs up the field within the cavity time constant.
- Very simple to implement in digital domain



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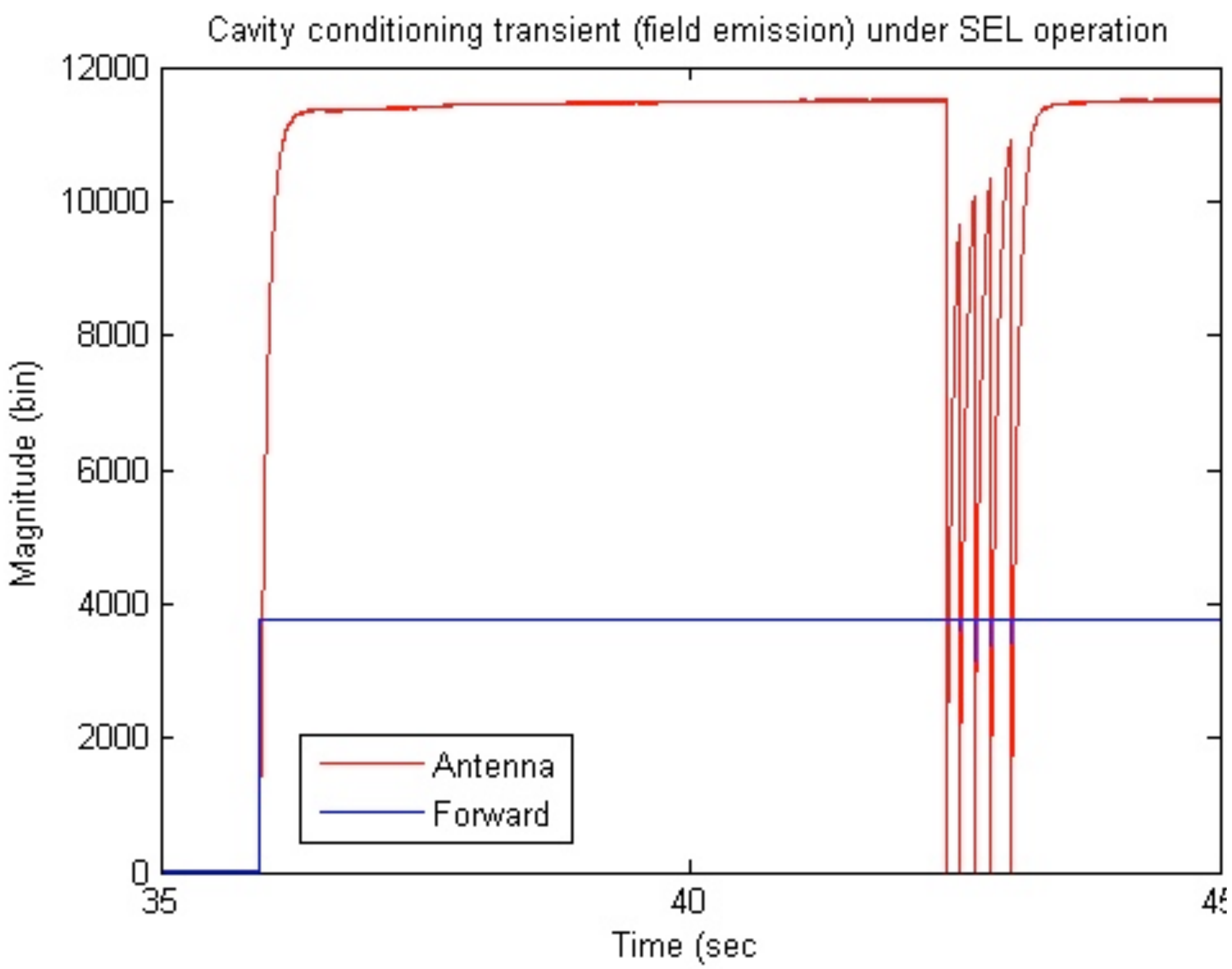
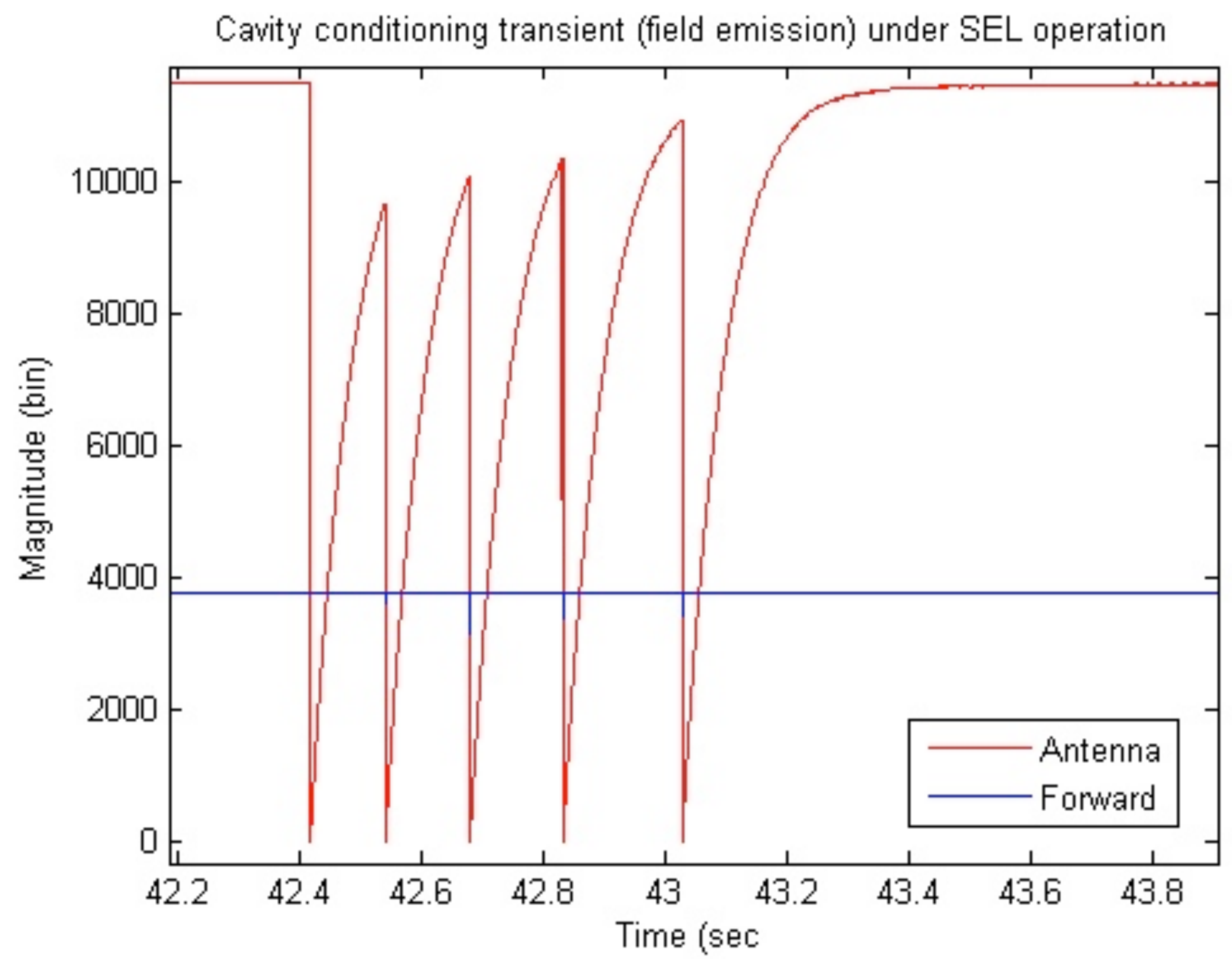
Cavity conditioning with SEL

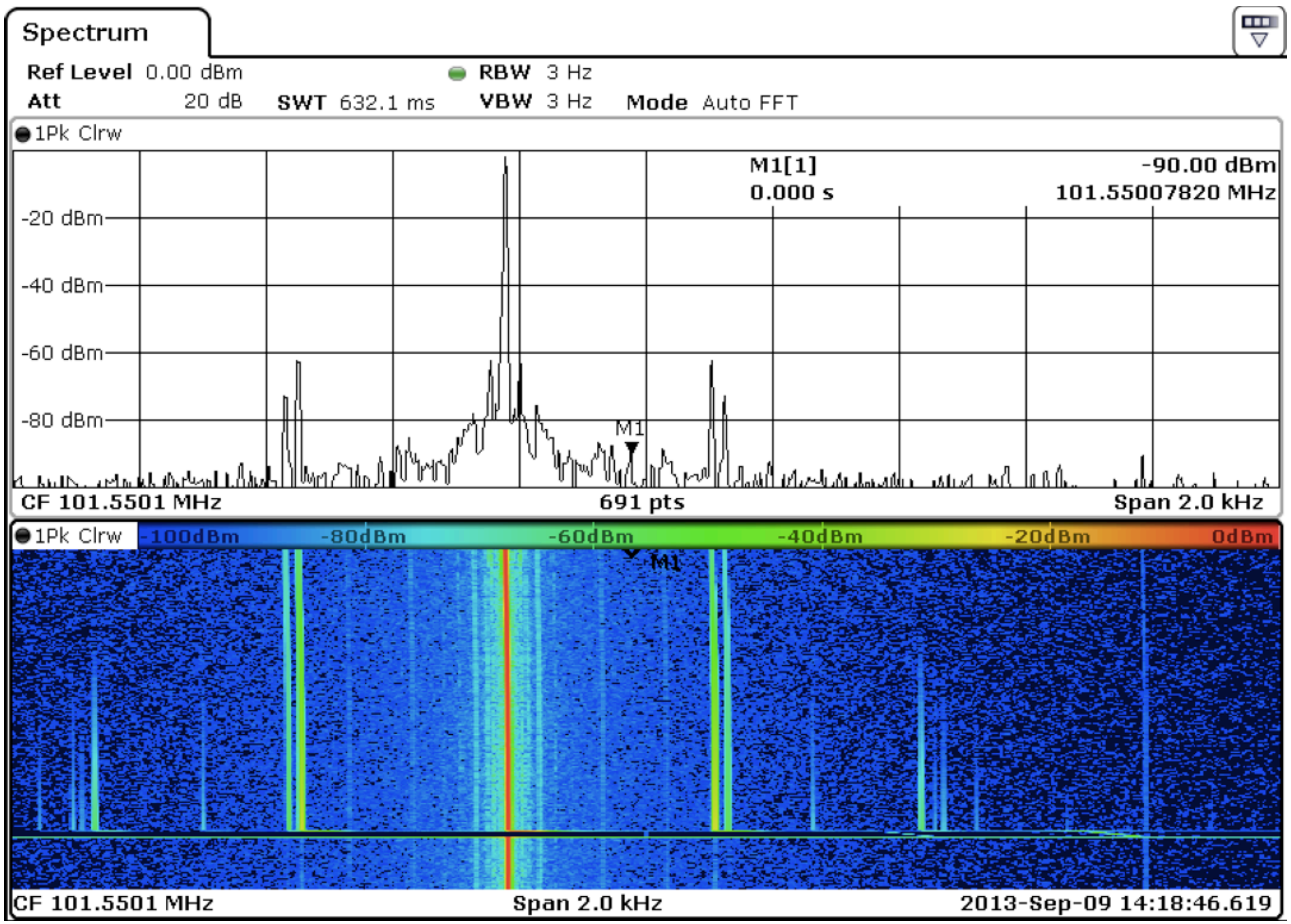
- Due to high LFD, cavity conditioning in “a traditional way” is difficult and ***very*** time consuming
- SEL allows to inject an desired amount of power under any conditions. Instant recovery from trips





Cavity conditioning with SEL

- Automatic conditioning algorithm on the way (X-ray emission monitoring)



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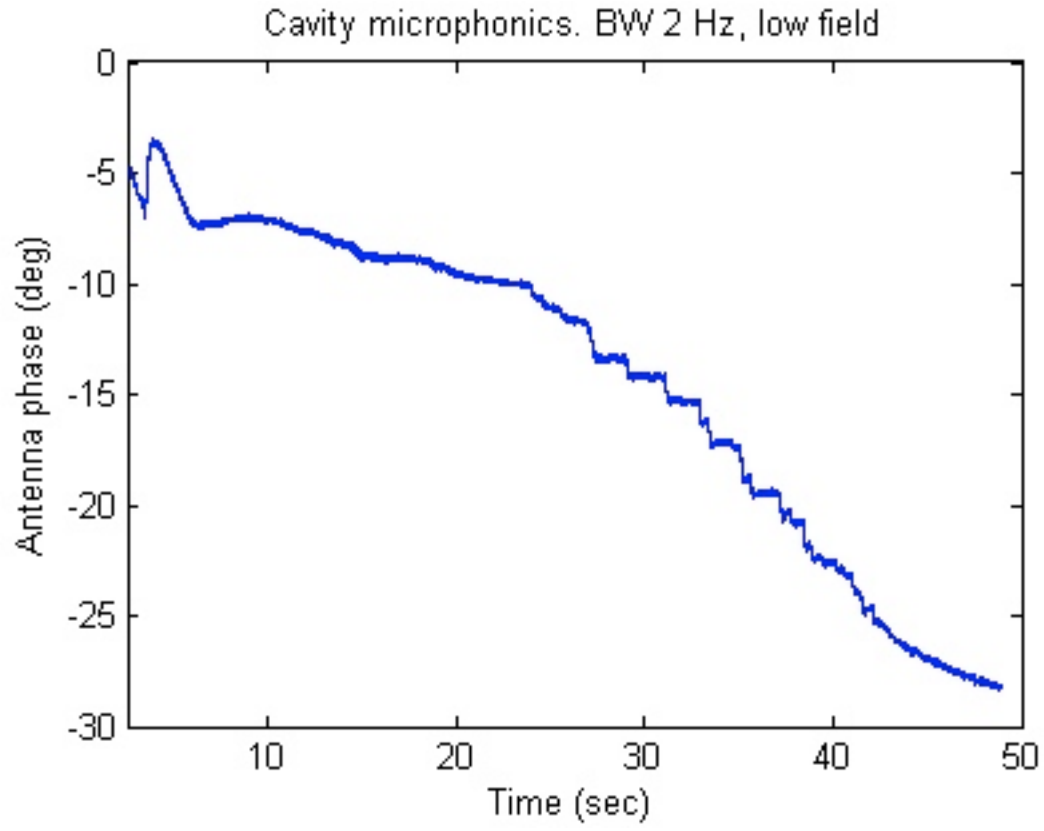
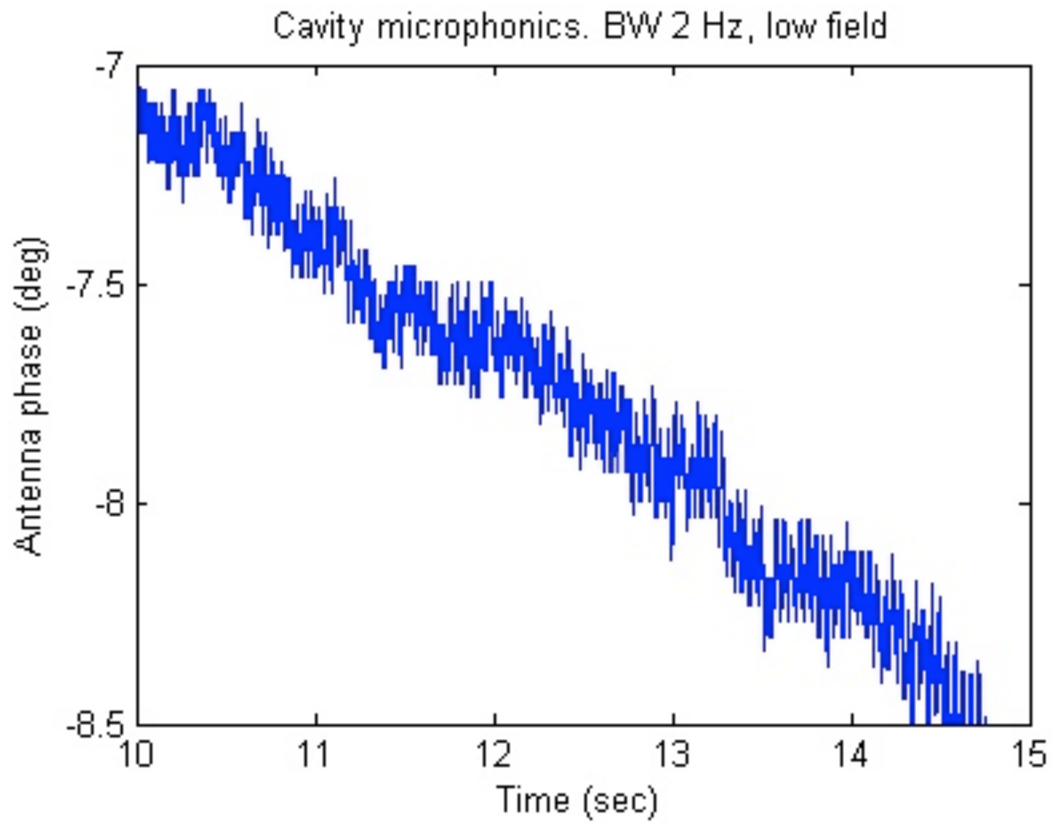
Microphonics measurements

- Results show much lower microphonics than anticipated
- Different behaviour at lower and nominal field, not completely understood yet





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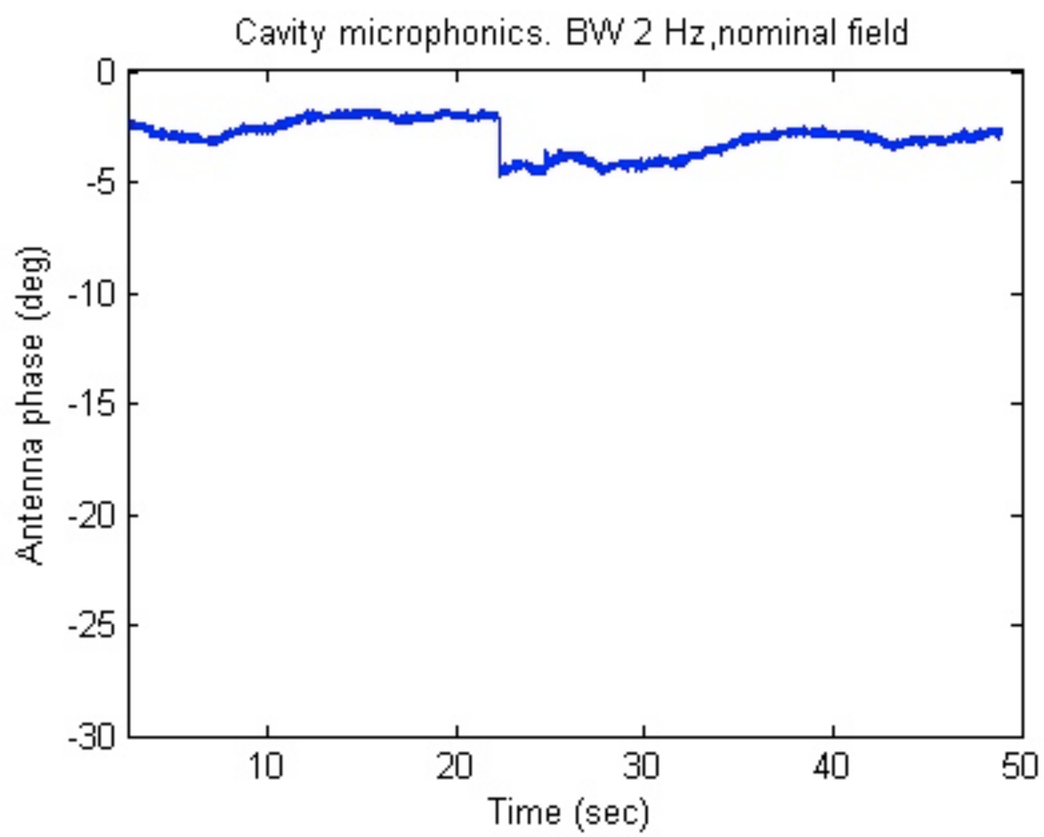

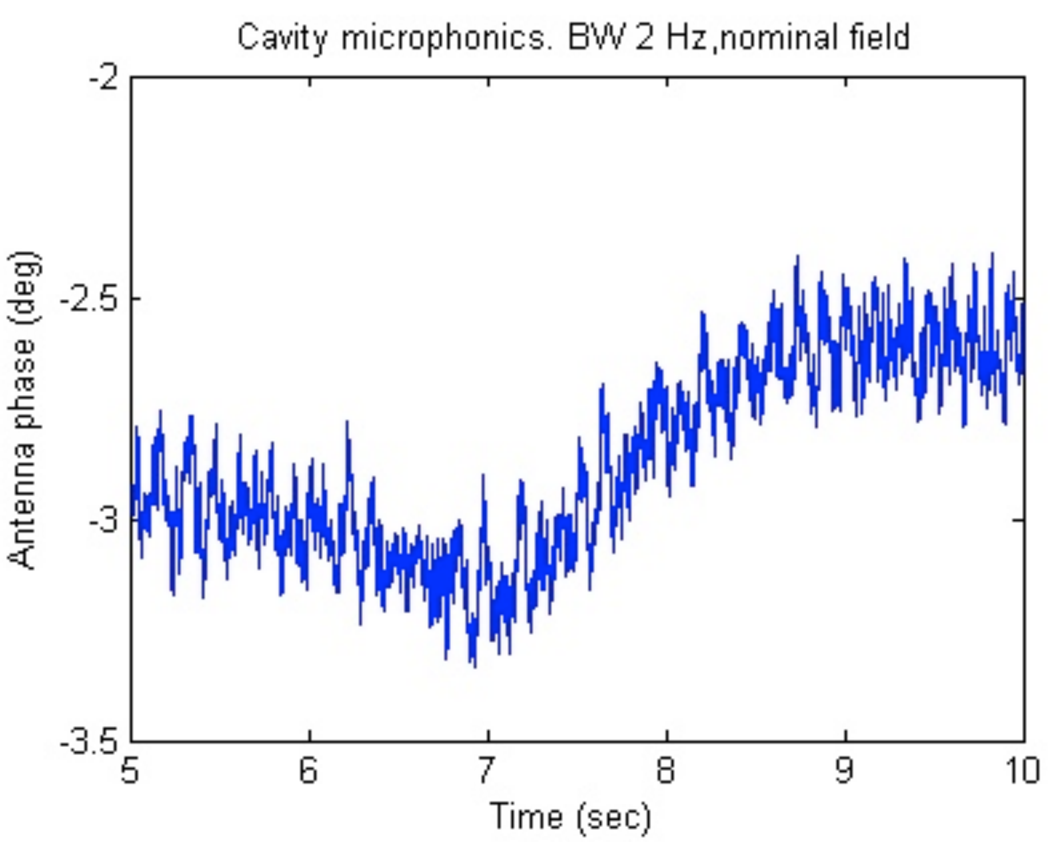

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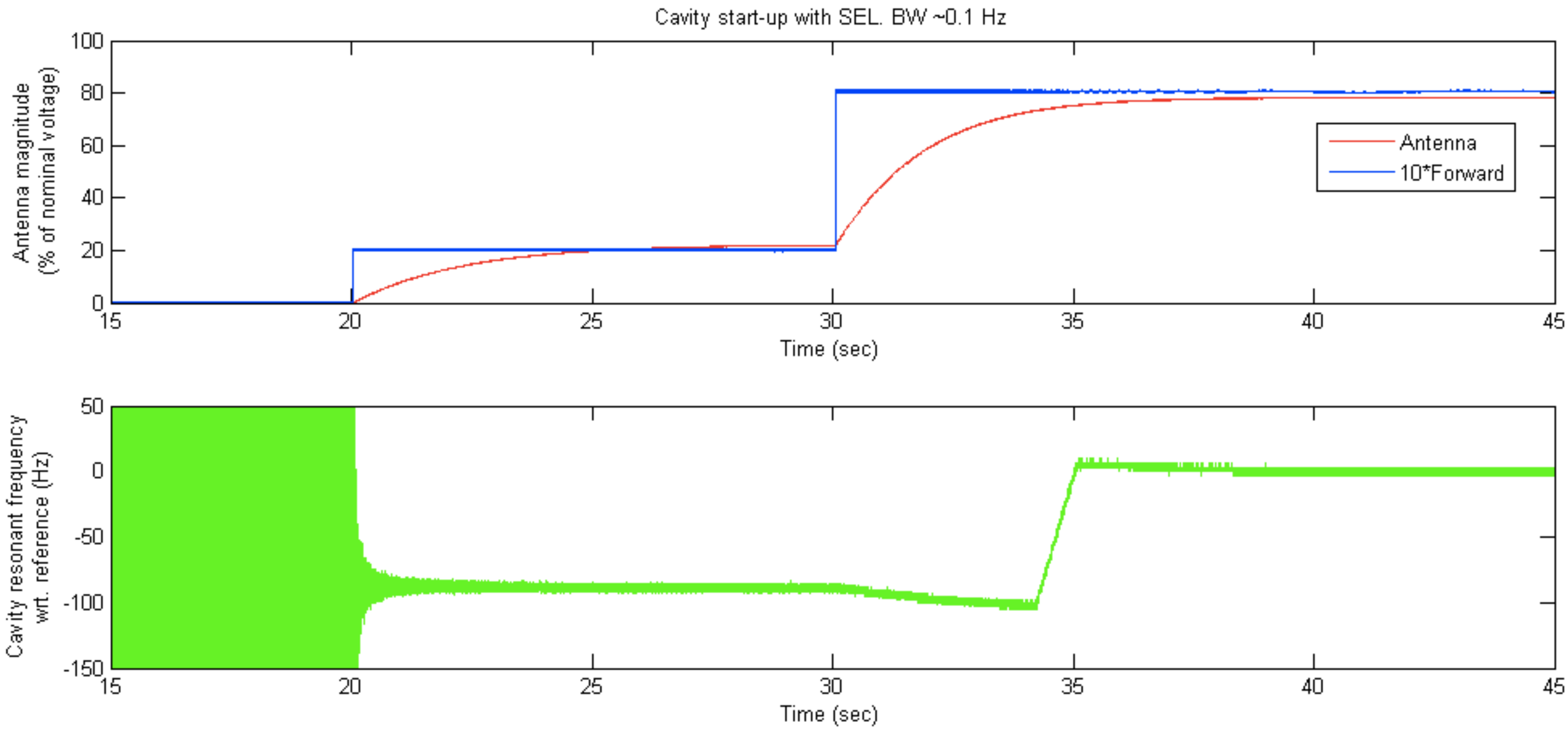
Automatic cavity start-up sequence



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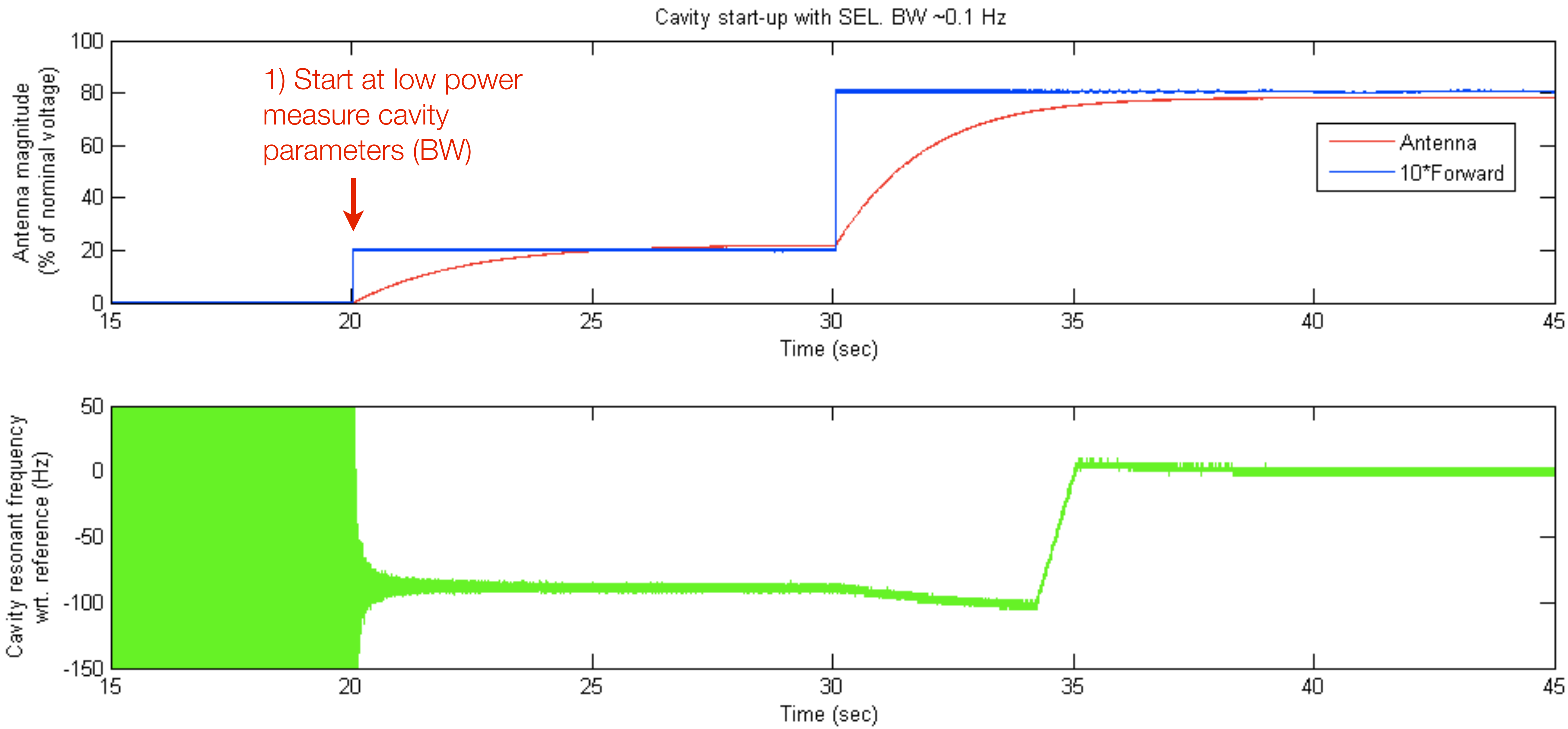

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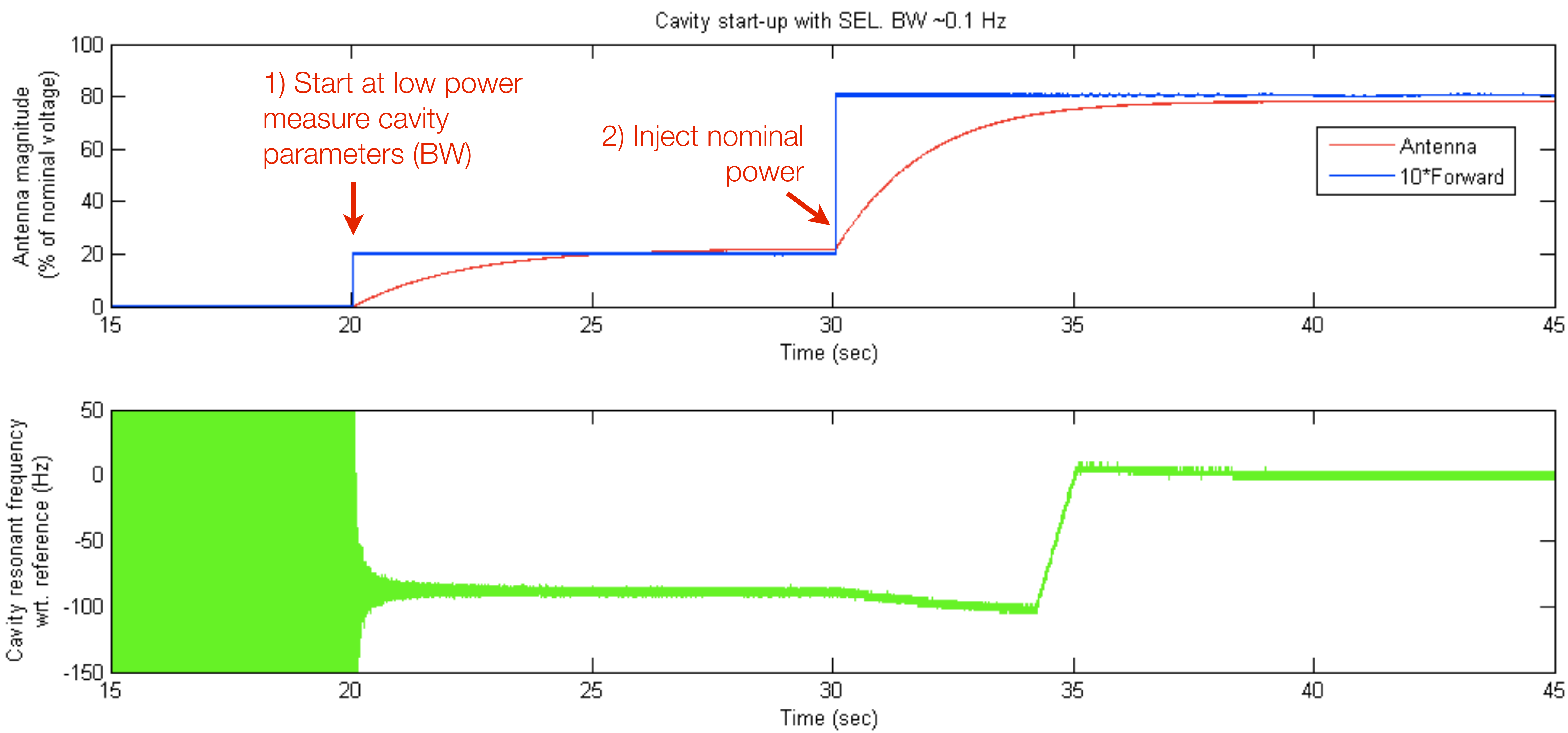

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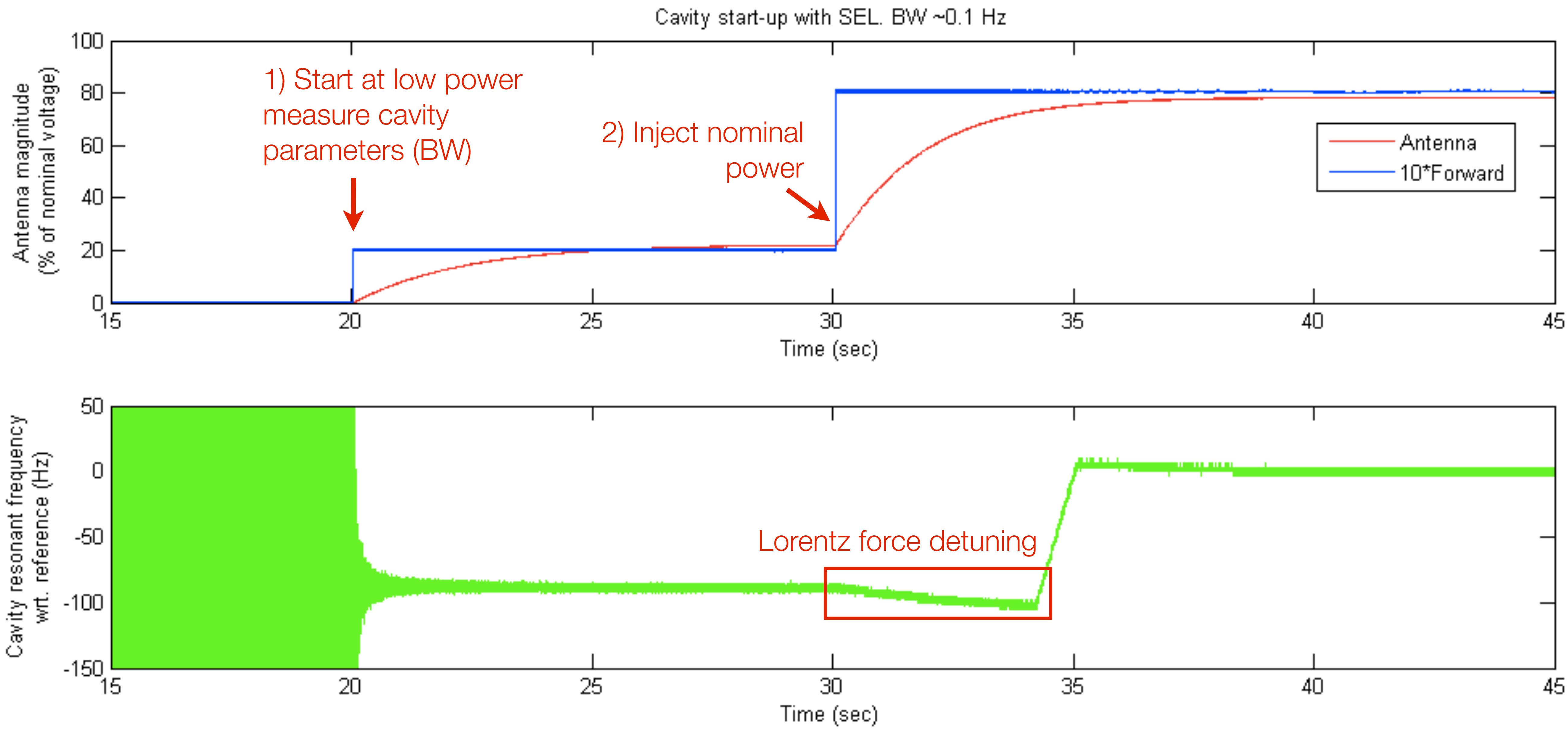

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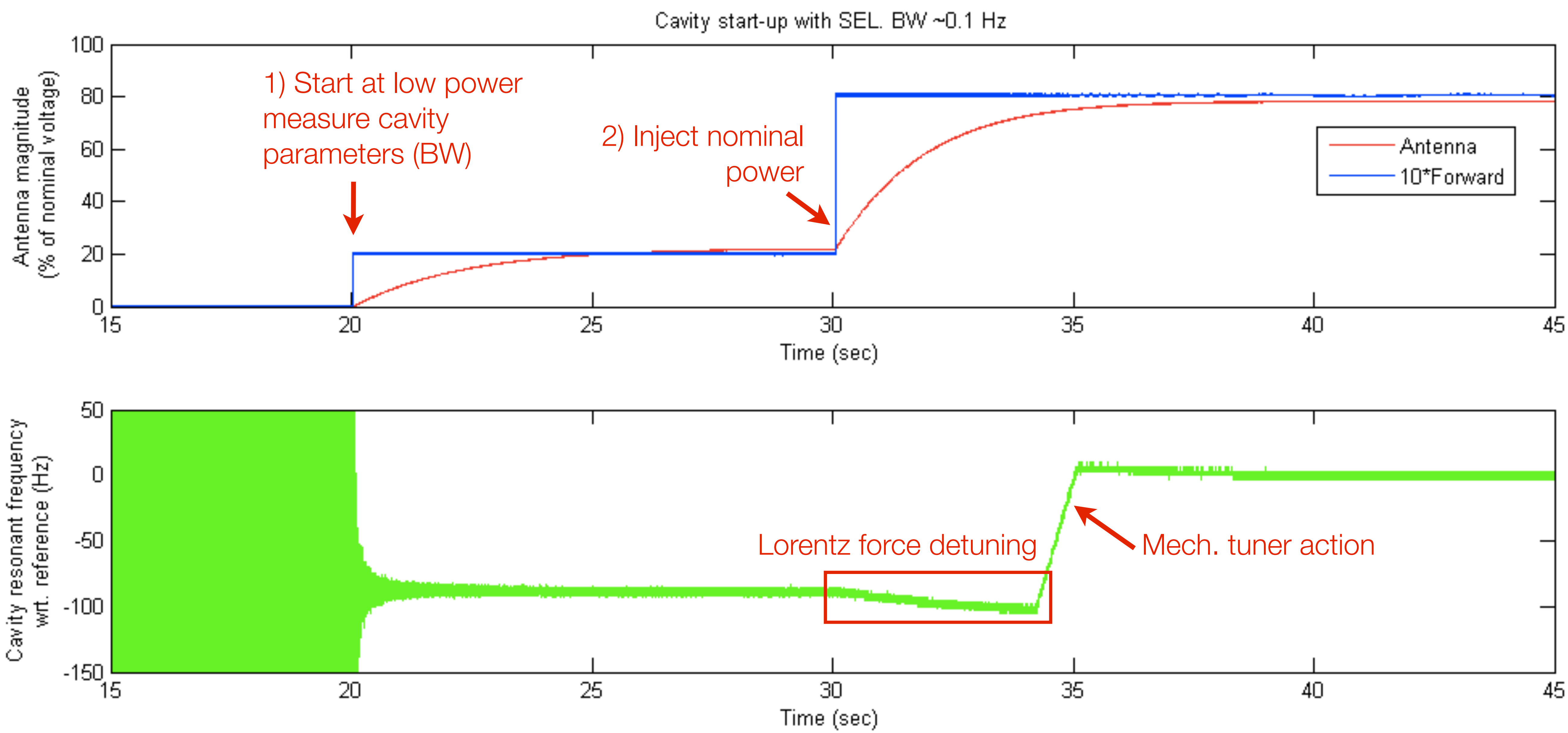

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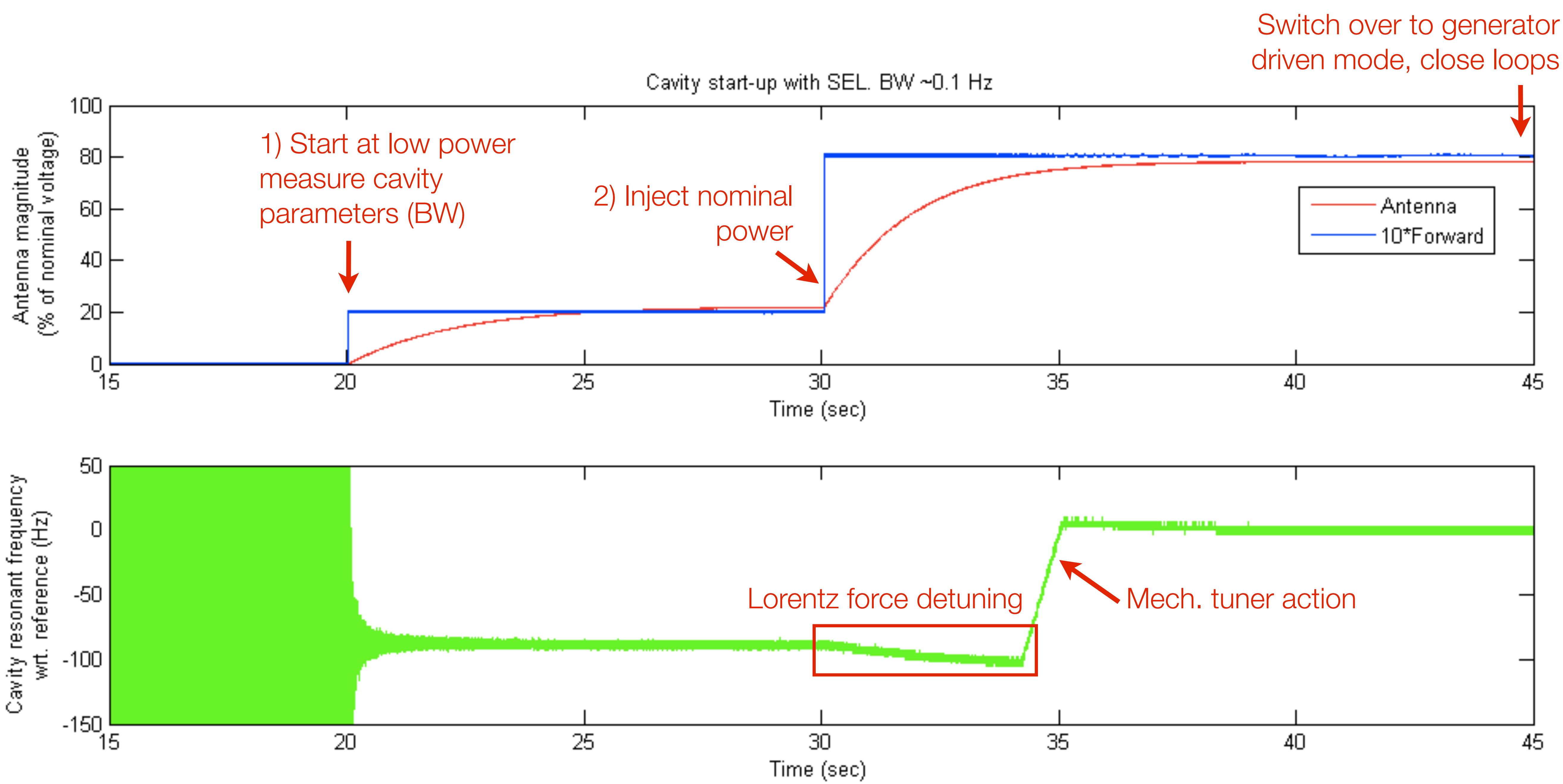

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Automatic linac phasing

- HIE Isolde may change the species and operating mode ***several times a day***
- With 32 cavities no room for manual setting up
- Robust RF design allowed for automatic linac phasing algorithm based on beam dynamics (M. Fraser)
  - Enter the species, desired energy, constraints on cavity voltage partitioning
  - The whole linac should set up automatically just by “pressing a button”
  - Tests on the current normal conducting structures successful

References:
M. Fraser et al.: Preliminary Beam Tests at REX for an Automatic Cavity Phasing Routine at HIE-ISOLDE
S. Haastrup et al.: An application for the automatic tuning of the RF cavities of the HIE-ISOLDE linac

On-going work

- Implementation of the feedback controller
- “Physicist-proof” design to minimize the need of RF expert interventions
    - OFF -> cavity start -> RF ON -> Linac Ready
    - Tuner design

- Finish integration (shielded racks, cooling/ventilation)
- Procurement of solid state amplifiers, cabling

- ***First RF in the machine expected in <12 months.***

Summary

- HIE Isolde is a 40MV radioactive ion beam post accelerator at CERN
- 32 Nb sputtered quarter wave resonators running at ~Hz bandwidth (@101.28 MHz)
- LLRF system fully digital (direct RF sampling/generation)
- Automatic linac setting up based on desired species and final energy
- Automatic cavity conditioning system with self excited loop
- Difficult cavity start up and handling procedure (SEL/tuning/feedback)
- Work on the way, first RF in the machine expected in <12 months

Thank you for attention

Abstract (not to be presented)

- **LLRF system for the HIE-Isolde**

Daniel Valuch, Michal Elias

The HIE-ISOLDE project is a major upgrade of the ISOLDE and REX-ISOLDE (radioactive nuclear beams) facilities at CERN. The most significant improvement will come from replacing most of the existing REX accelerating structure by a 40 MV superconducting linac based on 32 independently phased superconducting quarter-wave resonators (cavities). The new linac will raise the energy of post-accelerated beams from 3 MeV/u to over 10 MeV/u. The resonators operate at a frequency of 101.28 MHz and at a relatively high Q, providing an operational bandwidth of only a couple of Hertz. The resonators are tested and conditioned at their intrinsic Q providing bandwidth only of a fraction of a Hertz.

A new, fully digital LLRF system is being developed to operate the cavities at 0.2°/0.2% field accuracy. The very narrow resonator bandwidth introduces specific problems in cavity conditioning, measuring their parameters and the operation. A mechanical tuning system with a fraction of a Hz resolution and low microphonics is being developed to tune the cavity to the desired frequency. Lorentz force detuning of the tuning plate makes the cavity power up sequence, fast set point changes, as well as recovery from a sudden field loss very challenging. The cavity needs to be started up with a self-excited loop, undergo the mechanical resonant frequency tuning and be glitch-lessly handed over to the generator driven mode. The system design is presented along with the challenges and first results obtained on a cold cavity.

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